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The purpose of this research is to experimentally determine the diagnostic accuracy and clinical acceptability of digitally acquired mammograms displayed on soft copy display compared to laser printed hard copy. Implementation of state-of-the-art digital mammography and displays in the clinical setting are completed. We have investigated image display enhancement methods that have demonstrated improvement in feature detection in the laboratory. We are now evaluating eight different methods of image processing in a "preference" observer study using clinical digitally acquired mammograms. Based on the results of these data, we will proceed with a larger clinical trial to evaluate the timing and accuracy of soft copy and hard copy display methods.

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FOREWORD

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Introduction

a) Nature of the problem (from original text)

A full-field digital mammography system has been developed by Fischer Medical systems in collaboration with the University of Toronto. This scanning slot digital mammography system provides 50um, 12-bit pixels with inherently better contrast than that of conventional mammogram. The advent of digitally acquired mammograms offers the possibility of further improvements in early breast cancer detection. Specifically, digital acquisition systems decouple the process of x-ray photon detection from image display by using a primary detector that directly quantifies transmitted photons. This allows digital systems to be more efficient in utilization of radiation dose. Digital systems also allow a wide dynamic range so that a wider range of tissue contrast can be appreciated. Subtle contrast differences can be amplified and the distinction between benign and malignant might be increased. The new scanning slot digital mammography system has the further advantage of reduced scatter compared with both conventional and phosphor plate technologies. Furthermore, digital systems have the capacity to bring revolutionary advantages to breast cancer detection and management: 1) image processing for increased lesion conspicuity; 2) computer-aided diagnosis for enhanced radiologic interpretation; 3) teleradiology, or image transmission, as a means of bringing world-class expertise to community hospitals and remote areas; 4) improved image access and communication through digital image archiving and transmission; and 5) dynamic, or "real time" imaging for use during biopsy and localization procedures.

However, there are limitations to both laser-printed film and electronic displays, the two possible display methods for digital mammography. The best quality film printers can only display 87um pixels in an 8"X10" printing of the digital data. This would not provide sufficient spatial bandwidth for the available data. These printers may also lack sufficient greyscale bandwidth. The best possible 2560x2048 pixel monitors can generate over 170-680 nits luminance without pixel bloom. To gain access to the full grey scale bandwidth, monitor display would require intensity windowing, and to view the image at the full 50 mm spatial resolution, roaming and zooming would be necessary. Clearly, any display modality requires compromises that will effect diagnostic accuracy and interpretation speed.

b) Background of previous work (from original proposal)

For a number of years, the Medical Image Presentation research group at UNC-CH has been exploring various issues concerning the display of medical images. Early on we addressed the issues of standardization of display devices to assure legitimate comparison of various display methods under investigation. The display is perceptually linearized so that each intensity step in the acquired image is displayed as an equally perceptible step in the grey levels of the display [Pizer 1981, 1987, 1989, Johnston 1985, Rogers 1987]. In addition, our group, under another grant, (RO1 CA44060) has developed and experimentally evaluated the ergonomic and cognitive aspects of electronic workstations. We constructed a prototype workstation called FilmStrip using a single 2048x2560 pixel high-brightness monitor, a very simple interaction, and an extremely fast image display time (0.1 sec). A controlled subject experiment was used to evaluate FilmStrip relative to film and alternator [Beard 1993]. All reports were of clinically acceptable accuracy. Based on our experimental results, we are 95% confident that FilmStrip is no more than 1.5 minutes faster and no more than 30 seconds slower than film. This is the first time a radiology workstation has been shown to be as fast as film for interpretation of medical images under clinically realistic conditions. We have conducted a subsequent experiment

showing that a lower cost version of FilmStrip called FilmStriplet can also be clinically viable with sufficient training [Beard 1993].

Under a medical image presentation program project grant, (P01-CA47982), we have been exploring different image processing methods, specifically various versions of the Contrast Limited Adaptive Histogram Equalization algorithm, and have developed an experimental method to optimize the parameters for a given enhancement algorithm that takes into account the deleterious effects of image noise and that does not require the performance of a full clinical trial [Puff, 1992]. This work has involved the conduct of a number of image quality assessment experiments.

Under the previously described interactive Digital Mammography Development Group grant, Gray Scale Image Processing For Digital Mammography, (R01 CA 60193), we are conducting preliminary experiments to determine the effect of the variable amount of radiographically dense breast tissue, the mammographic characteristics of various lesion types, and the location of lesions within the breast on the choice of appropriate intensity windows and other image processing algorithms selected for electronic viewing of mammograms. The results of this investigation will also give us some indication of the number of intensity windows that might be useful, or needed, for display of the recorded digital information.

c) Purpose of present work

The purpose of this study is to determine experimentally the diagnostic accuracy and interpretation speed of the available display methods.

d) Methods of approach

We propose to conduct an ROC study involving the best available display methods, one representative of a film based display, and one using the best available state-of-the-art electronic workstation.

Body

a) Accomplishments to date

1. To achieve the goals of this research, we propose using full field digitally acquired mammograms. Availablity of the clinical digital units were delayed because of detector upgrades and manufacturing problems. However, our Fischer unit was installed at UNC Hospitals in April of 1997. In Jan. 1998 Fischer upgraded the system with a new detector that improved resolution and reliability of the system. To date we have acquired more than 300 clinical mammograms.

2. During the first part of this grant, a number of changes in the state-of-the-art of monitor technology occured, a) High brightness/resolution monitors, although commercially available, have not been as readily available as once promised. There are manufacturing problems in quality assurance and meeting performance specifications. We have evaluated a number of different brands in our laboratory and with collaboration of Dr. Hans Rhoerig at Univ. of Arizona and Dr. Harwig Blume at Philips Medical. As a result of these extensive evaluations, we purchased two DataRay and two Orwin monitors. To achieve the maximum displayable grey -levels, we installed the electronics from Dome (10 bits grey level). We have developed interactive software that provides a viable mammography workstation. This software has been completed and tested. We expect to begin the actual ROC observer studies within the next few months.

3. We are in the final stages of preparation for a "preference" observer study to evaluate eight different methods of image processing for display of digitally aquired mammograms.

The mammograms will be displayed on laser printed film that has been standardized to the softcopy display. The eight different techniques are as follows: 1) hadn intensity windowing, 2) Peripheral equalization followed by hand intensity windowing, 3) unsharpmasking followed by hand intensity windowing, 4) Contrast Limited Adaptive Histogram 5) Mixture moldeling based intensity windowing, 6) Hhistogram based intensity windowing, 7) MUSICA and 8) TREX propriatery processing method. The study will be with 10 radiologist observers and 60 single breast images each processed with the 8 different methods. There are 20 images from each of the three digital mammography systems, GE, TREX and Fischer.

b) Research to be accomplished

1. Upon completion of the preference study, we will select the best one or two processing techniques for image display. Then a larger clinical trial (about 200 cases) will be carried out to compare images obtained with the digital mammography system to images obtained by conventional x-ray mammography. A second study, running in parallel, will compare hard copy film to images displayed on the workstation. This larger clinical trial should be begin about November this year (1998).

2. Timing and accuracy data will be obtained for comparison between the soft copy and hard copy display methods.

3. Analysis of these data will be accomplished with a final report by the end of the 5th year.

Conclusions

Although we have had delays in accomplishing the original goals of this research, we have refined the research protocols to provide more efficient studies, instrumentation has become available (mammographic laser printers, quality high-brightness monitors, and DACS) that allow us to better investigate the display issues proposed.

With the addition of the "preference" study, we have been able to broaden the scope of types of image processing included in the initial trials and, therefore select the best image processing method from a larger group of candidates than we had originally proposed.

With the one year extension of this grant we will be able to accomplish the goals of the proposed research.

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